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Changes in the Gonial Region Induced by Alterations of Muscle Length

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Thirty-eight adult rhesus monkeys were used in the study of osseous remodeling of the gonial region following various types of experimental intervention. This study indicated the following: (1) When the length of the masseter muscle is increased by increasing the vertical dimension, resorption in the gonial region takes place. (2) When the original length of the masseter muscle is increased by an appliance and a sham operation is performed, increased resorption, greater than that observed when only an appliance is used, is observed. (3) When a muscle is detached following an increase in vertical dimension and allowed to reattach spontaneously, the largest amount of gonial remodeling is observed. These observations indicate that both blood supply and function influence the shape of the gonial region.

Some relapse occurs after nearly every type of orthognathic surgical procedure currently performed. Moreover, the number of different procedures available for the same condition suggests that there is no agreement as to which factors are involved in postsurgical instability. However, most investigators believe that interruption of vascular supply and changes in muscle relationship are two of the major factors.

The Role of Blood Supply. The effect of various orthognathic surgical procedures on the blood supply to the associated osseous segments is unclear. Bell and Kennedy[1] have shown that in an experimental ramus osteotomy in adult rhesus monkeys, necrosis occurred in the segments even when they were well pedicled. Boyd et al[2] removed the origin of the temporalis in guinea pigs to eliminate muscle tension on the coronoid process while still maintaining blood supply. In the majority of the experimental animals, there was no change in the size or shape of the coronoid process. Those workers concluded that the shape was therefore dependent on blood supply more than on functional forces. Warner[3] also studied the relative roles of blood supply vs functional factors in determining bony shape and form by blocking the nerve supply to the temporalis muscle with alcohol. He observed that a loss of muscle function resulted in altered bony form of the cranium and mandible. His results support the thesis that muscle function directly influences bone form, as opposed to the view that surgical extirpation of a muscle interrupts the vascular supply to the associated osseous elements and that it is this interruption which influences skeletal remodeling.

The Role of Muscle and Other Soft Tissues. The muscles attached to the maxillomandibular complex have been cited as a major factor in relapse following orthognathic surgery. During surgery these muscles are often abruptly altered, being lengthened, shortened, or changed in their direction of movement. Any muscle or muscle group that has been elongated within physiologic limits will attempt to reestablish functional homeostasis.[4] McNamara et al[5] and Carlson et al[6] have stated that musculoskeletal homeostasis can be reestablished through adaptive mechanisms in four ways: adaptation within the central nervous system,

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adaptation within a muscle, adaptation at the muscle/bone interface, and adaptation within or between osseous attachments. The last-named mechanism of adaptation is most germane to this study and will be considered in detail.

Two types of skeletal adaptations after orthognathic surgery have been observed. The first type is osseous displacement, the mechanism by which the spatial orientation of a bone is altered in relation to one or more adjacent bones.[7] If the bones act as muscle attachments, osseous displacement can result in alteration in the length of the associated musculature. The second type of skeletal adaptation is localized bony remodeling.[7] Through the process of regional bone deposition and resorption, the size and shape of an individual bone is altered. Hoyte and Enlow[8] maintain that the detailed shape of any bone is a result, in part, of patterns of muscle forces acting upon it, causing resorption and/or deposition. Najjar and Kahn[9] imply that the speed of remodeling and healing of various bones in animal models depends upon the nature of the soft tissue forces to which the bones are subjected. As noted by Carlson and co-workers,[6] osseous displacement is most likely to affect short-term stability following orthognathic surgery. Once bony healing has taken place, however, localized remodeling is the most likely mechanism by which alteration in skeletal form takes place.

Kelsey,[10] Cunat and Gargiulo,[11] and Astrand and Ridell[12] believe that functional factors play an important role in determining the configuration of the skeletal elements after surgery. They observed that the original gonial angle of the mandible tends to return following orthognathic surgical procedures. Kelsey[10] suggests that this tendency is the result of tension produced by the pterygomasseteric sling, dictating a postsurgical return of the original gonial angle through progressive movement of the osseous elements. Hoyte and Enlow[8] maintain that the detailed shape of any bone is partially a result of patterns of muscle forces acting upon it.

Thus, it seems that two major factors can influence the amount of localized bony remodeling in a given area: functional factors and vascular factors. The purpose of this study is to examine in an animal model certain adaptations that occur in the gonial region of the mandible after orthognathic surgery. Remodeling in the gonial region is often seen following such surgery, but why it occurs is not completely clear. Most likely, the combined effects of alteration of local blood supply and changes in functional demands placed upon the osseous elements by the associated musculature are contributory factors. The relative roles of these two factors in gonial remodeling are considered in this study.

Table 1. Schedule for Destruction of Animals

Experimental Groups	Times				
	4 wk	8 wk	12 wk	24 wk	48 wk
C	1	0	3	3	0
As	1	1	1	2	1
A	0	0	0	0	0
AD	1	2	2	2	1
DR	1	1	1	2	1
ADR	1	1	1	2	1
PT	1	1	1	1	1

Materials and Methods

To investigate specific adaptations in the craniofacial region that occur subsequent to the alteration of masticatory muscle length, an experimental protocol, previously developed by McNamara[13] and Yellich et al,[14] was used.

Experimental Animals

Thirty-eight adult rhesus monkeys (*Macaca mulatta*) were used in this study. The animals were at least four and a half years of age, based on the tooth eruption scales developed by Hurme and Van Wagenen.[15] The animals included those used by Yellich et al[14] in their study of muscular adaptations. In addition, another experimental group was added.

The 38 experimental animals were divided into a control group and six experimental groups. They were killed at specific intervals according to the schedule illustrated in Table 1. In a few cases, the animals belonged to more than one of the groups.

Group C: Control. Baseline values were established with this group of seven untreated animals.

Group AS: Appliance and Sham Surgery. The six animals in this group received a maxillary onlay bite-opening appliance and also underwent a sham surgical procedure, which consisted of dissection to, but not including, the masseter muscle. The appliance was used to increase the length and change the orientation of the pterygomasseteric musculature.

Group A: Appliance Only. The vertical dimension of the five animals in this group was altered with an appliance as in Group AS, but there was no surgical intervention.

Group AD: Appliance and Detachment. A bite-opening appliance was cemented in the maxilla of eight animals one day prior to surgery. The masseter muscle was surgically detached bilaterally, and no attempt was made to reestablish the original position of the pterygomasseteric sling. (See Yellich et al[14] for a complete description of the surgical procedure).

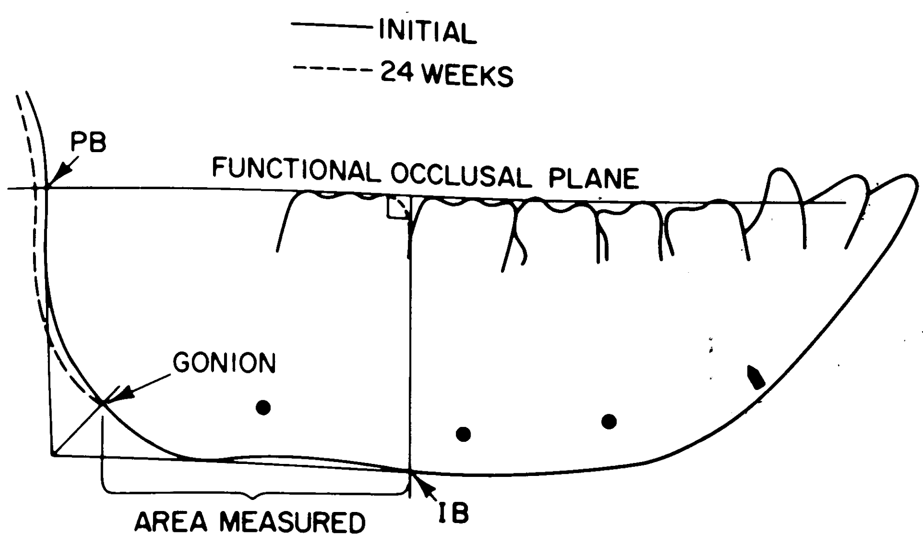


FIGURE 1. Method of calculating bone deposition and resorption in the gonial region. A vertical line is constructed perpendicular to the functional occlusal plane through the distal contact point of the lower second molar, intersecting the inferior border of the mandible at point IB. Tangential lines are then constructed to the gonial region from point IB and point PB (the intersection of the functional occlusal plane with the posterior border of the mandible). The angle of their intersection is bisected, and the gonion established. The area measured by planimetry extends from the gonion anteriorly to point IB. Changes in contour are measured in millimeters squared.

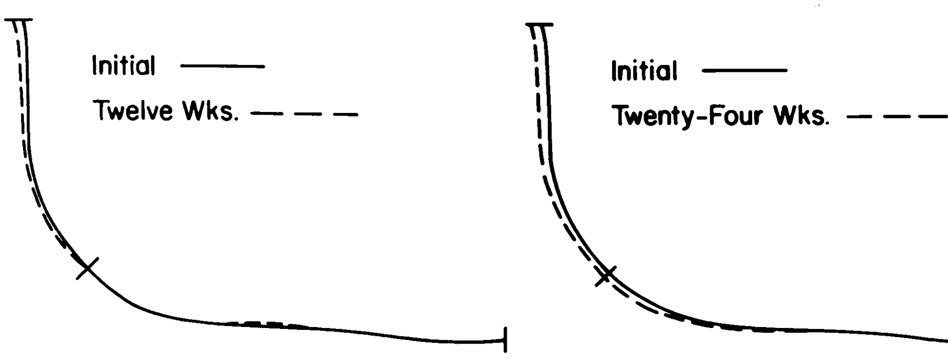


FIGURE 2. Typical patterns of gonial remodeling observed in control animals. Superimposition is on the mandibular implants (not shown).

Group DR: Detachment and Reattachment. The masseter muscle was surgically detached bilaterally and reattached at the gonial angle in its original position in six animals. There was no alteration in muscle length.

Group ADR: Appliance, Detachment, and Reattachment. A bite-opening appliance was cemented one day prior to surgery in the six animals in this group. During surgery, the masseter was detached bilaterally and then surgically reattached to the fascia of the pterygomasseteric sling at a distance slightly longer than its original resting length.

Group PT: Post-treatment. To examine whether increasing the resting length of the masseter muscle would cause irreversible bony remodeling at the gonial angle, the five animals from Group A had their appliances removed after 24 weeks. They were then examined at selected intervals after appliance removal.

Implant Techniques

Tantalum implants were placed by the method developed by Björk[16,17] and modified by McNamara et al.[18,19] At least four implants were placed in the mandible, one in the symphyseal region, two in the corpus, and one in the ramus. The mandibular implants were used in the superimposition of tracings of serial cephalograms to monitor osseous changes.

Cephalometric Techniques

Serial cephalograms were taken by use of a cephalometric headholder specifically designed for nonhuman primates.[20] Type M industrial film was used for greater definition of structures. The radiographs were made into Translite films, which were enlarged three times the original radiograph size. This process was included to minimize tracing errors and increase the accuracy of the quantification of small changes.

All animals were radiographed preoperatively, immediately postoperatively, and at 4, 8, 12, 24, 36, and 48 weeks, or until they were killed. Skeletal changes were quantified by measuring superimposed tracings of the enlarged cephalograms, using the preoperative radiograph as the baseline for comparison.

Table 2. Bone Remodeling by Group and Postoperative Interval

Group	Interval (Weeks) 4	8	12	24	36	48
Control (C)						
N	5	3	6	5	—	—
x̄	+0.7	−1.1	−0.7	−1.1	—	—
SD	2.8	3.3	2.8	5.4	—	—
Appliance, sham (AS)						
N	5	5	4	3	1	1
x̄	−8.0	−11.7	−13.3	−16.3	−25.0	−28.0
SD	8.2	5.9	11.0	10.3	—	—
Appliance (A)						
N	5	3	5	5	—	—
x̄	−2.7	−5.9	−6.7	−8.7	—	—
SD	4.1	3.5	5.6	5.4	—	—
Appliance, detach (AD)						
N	8	7	5	2	1	1
x̄	−13.3	−20.8	−22.9	−34.5	−30.0	−31.0
SD	9.1	11.9	7.1	1.6	—	—
Detach, reattach (DR)						
N	5	5	4	3	1	1
x̄	−6.7	−13.1	−9.7	−10.4	−7	−9
SD	2.3	9.6	6.7	2.8	—	—
Appliance, detach, reattach (ADR)						
N	6	5	4	3	1	1
x̄	−11.1	−20.0	−18.3	−20.0	−27.0	−30.0
SD	13.2	20.7	10.4	10.9	—	—
Post-treatment (PT)						
N	5	4	3	3	1	1
x̄	1.6	3.9	5.9	2.9	5.0	5.5
SD	3.0	3.9	2.6	2.5	—	—

Accumulated data: N = number of animals, x̄ = area in mm^2, SD = standard deviation.

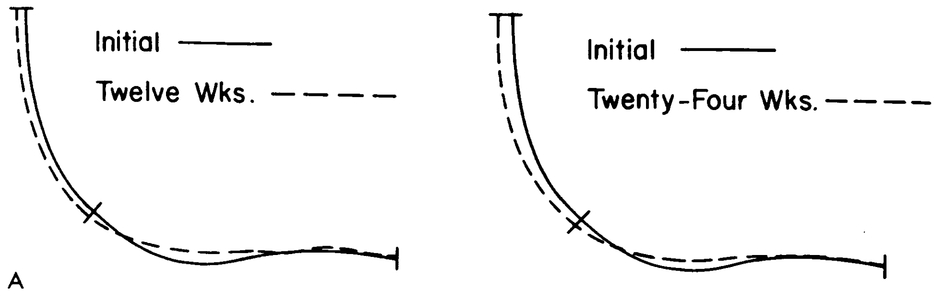
Fabrication of the Maxillary Appliance

Upper and lower alginate impressions were taken on those animals in which the vertical dimension was to be altered (Groups A, AS, AD, and ADR). A bite registration was taken so that the bite was open 15 to 17 mm interincisally. From these casts was constructed a bite-opening appliance of the same type as that used in our previous studies.[5,13] These appliances were cemented to the maxillary teeth on the day preceding surgery.

Method of Analysis of Gonial Remodeling

To determine what remodeling changes occurred in the gonial angle in each experimental group, a method of analysis was devised to encompass the attachment of the masseter muscle.[18] The line of the occlusal plane was extended so that it would intersect with the posterior border of the ramus of the mandible (Fig. 1). A vertical line was drawn perpendicular to the occlusal plane inferiorly, just contacting the distal surface of the permanent second molar and intersecting the lower border of the mandible. The arch represented by that portion of the border of the mandible intersected by the two lines was divided by a line bisecting the gonial angle. The limits of the area studied were determined by the anterior vertical line and the line bisecting the gonial angle. Although not the entire extent of the masseter insertion along the border of the mandible was included, this area was chosen to eliminate as much as possible the small amount of growth that was anticipated to occur in some of the animals in the age group studied.[18]

The amount of bone deposition or resorption at the gonial region was measured on composite tracings of serial lateral cephalograms. It was thought that the two-dimensional measurements would give a reasonable indication of the actual three-dimensional remodeling occurring in the gonial region. Changes in area were measured with a planimeter that was adapted to measure in square millimeters. The measurements were repeated three times for each area. Results for each group were averaged, and a standard deviation was calculated. Differences between groups were considered significant when the calculated significance was at least at the 95% confidence interval. The data were statistically analyzed only through the 24th week because just one animal was observed after that time.



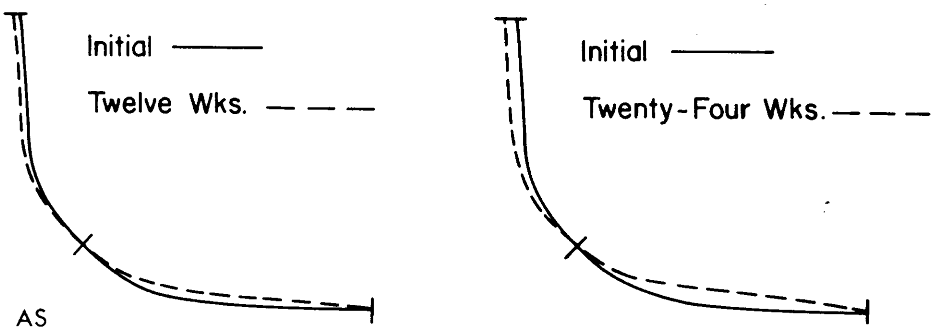
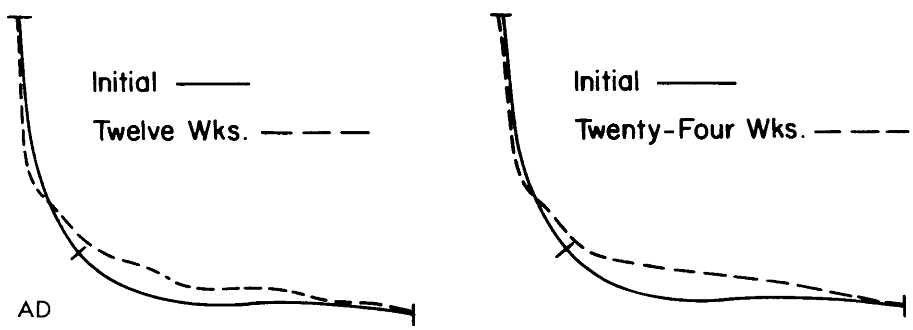


FIGURE 3. *Above*, typical patterns of gonial remodeling in the Group A animals.

FIGURE 4. *Center*, typical patterns of gonial remodeling in the Group AS animals.

FIGURE 5. *Below*, typical patterns of gonial remodeling in the Group AD animals.



Results

Adaptations in the gonial region were seen in each experimental group, the nature of the adaptations depending upon the experimental procedures performed. Resorption of bone was seen in all experimental groups except Group PT, in which an increase in bone deposition was observed. By 24 weeks, the change in area at the gonial angle was significantly different between all of the experimental groups (except PT) and the control group.

Group C. The control group of animals showed minimal remodeling in the gonial region during the period studied, averaging approximately 1 mm of resorption at eight to 24 weeks (Table 2, Fig. 2.).

Group A. This group, in which the elevator musculature was lengthened without any type of surgical procedure, showed the smallest remodeling change after both four weeks and 24 weeks, with a loss of 2.7 and 8.7 mm^2, respectively (Fig. 3 and Table 2). The rate of change was gradual but consistent. However, statistically, the values for Group A were different from the control values only after 24 weeks.

Group AS. Initial remodeling of the gonial region in the animals of this group was rapid, with a decrease of 8.0 mm^2 (Fig. 4 and Table 2). This was approximately 50% of the entire decrease seen at the end of 24 weeks. The remodeling continued after 36 and 48 weeks in the one remaining animal in this group, with decreases of 25 and 28.0 mm^2 observed. The rate of change was less but steady after the initial resorption. Group AS was significantly different from the control values after 12 weeks and remained so after 24 weeks.

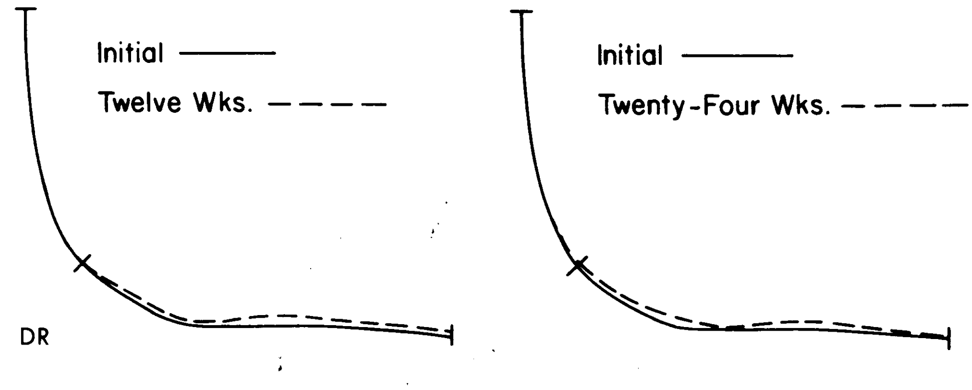


FIGURE 6. *Above,* typical patterns of gonial remodeling in the Group DR animals.

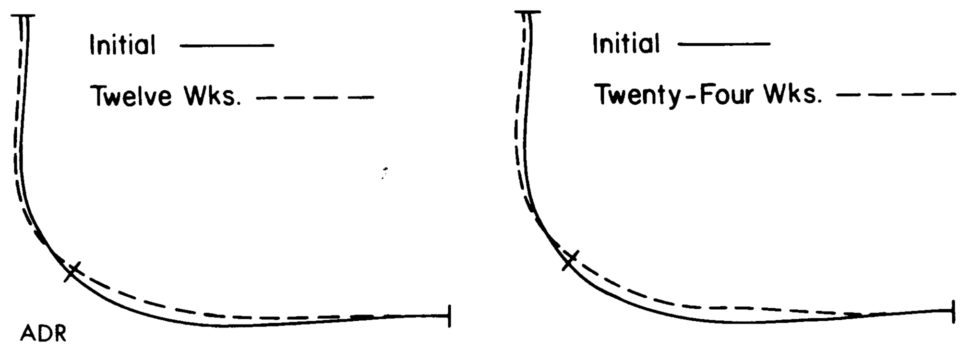


FIGURE 7. *Center,* typical patterns of gonial remodeling in the Group ADR animals.

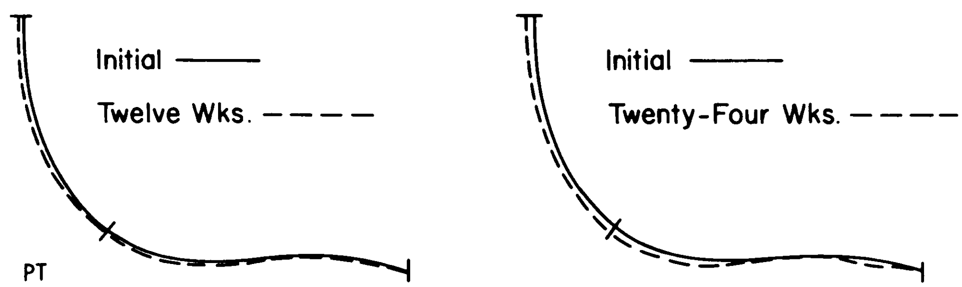


FIGURE 8. *Below,* typical patterns of gonial remodeling in the Group PT animals. Notice deposition of new bone.

Group AD. The largest amount of initial remodeling occurred in this group, in which an average of 13.3 mm^2 of bone resorption was observed (Fig. 5 and Table 2). In addition, at 24 weeks this group showed the largest decrease in area (of 34.5 mm^2). The amount of resorption measured after eight weeks was approximately 60% of that occurring at 24 weeks. The values for Group AD were significantly different from both control values and those of Group A after four weeks; significantly different from Groups C, AS, and DR after 12 weeks; and significantly different from all the groups after 24 weeks.

Group DR. Some remodeling at the gonial region was observed in this group during the first eight weeks of the experimental period (Fig. 6 and Table 2). There was 6.7 mm^2 of bone resorption at four weeks and 13.1 mm^2 at eight weeks. There was minimal further resorption after that time. Group DR values were significantly different from those of Groups C and AD after 12 weeks and remained so after 24 weeks.

Group ADR. The amount of bone resorption initially observed in this group was the second largest among the experimental groups (Fig. 7 and Table 2). In addition, all bone resorption occurred during the first eight weeks. After 4 weks, 11.1 mm^2 of resorption was observed, and after eight weeks, 20.0 mm^2.

Group PT. As indicated earlier, this group consisted of animals in which the vertical dimension was lengthened with an appliance, which was worn for 24 weeks. After the appliances were removed, bone deposition, rather than bone resorption, was observed (Fig. 8 and Table 2). However, the values for the PT group were not significantly different from those of the control group during any of the experimental intervals.

Discussion

The results of this investigation indicate that significant remodeling occurs at the gonial angle of the mandible following an increase in the length of the masseter muscle, with or without surgery. The rate of change seems to depend on whether the masseter muscle is surgically detached and whether it is surgically reattached or reattaches spontaneously.

The Effect of Muscle Detachment

Detaching and reattaching the masseter muscle without alterations of the muscle length (Group DR) resulted in a relatively rapid loss of bone at the gonial angle. Yellich et al[14] have shown that this muscle assumes a slightly shorter resting length after surgical detachment and reattachment at the same location. Whether the bone located below the new attachement represents the bone lost in the remodeling process is not known. The speed of the loss and the apparent completion of the process by eight weeks corresponds roughly to the completion of the inflammatory process, healing, and revascularization.

When surgical detachment and reattachment of the masseter muscle was combined with an experimentally induced increase in muscle length (Group ADR), there was rapid remodeling, which was greater in magnitude than that in Group DR, in which there was no experimental alteration in muscle length. The rate of change of the remodeling process decreased to nearly zero after the initial rapid change. Altering the original muscle length and surgically detaching the masseter muscle without surgically reattaching it (Group AD) resulted in an initial rapid loss in area at the gonial angle, which was greater still than in Groups AD and ADR. In this case, however, the remodeling continued throughout the experimental period, although the rate of change seemed to decrease.

The most obvious result of detachment of muscle from the underlying bone is the interruption of local blood supply. Bell and Kennedy[1] showed that interruption causes necrosis, which may be followed by resorption. Boyd et al[2] concluded that the shape of some bones is dependent upon blood supply. The role of inflammation and its effect upon remodeling has not been studied extensively; the inflammatory process may also have some input into the balance between resorption and deposition. Clearly, however, the dynamic process of deposition and resorption of bone is affected by both local and regional factors.

The Effect of Altered Muscle Length

Altering the length of the masseter muscle without surgically detaching it (Groups A, AS) caused initial resorption, which continued at a slower rate than in the groups in which surgical detachment was performed. In addition, the rate of change remained nearly constant as opposed to that seen in the groups in which the masseter was detached (Groups AD, DR, ADR). The reasons for the resorption are not completely clear but probably involve several factors, among which are increased forces acting upon the osseous elements, perhaps leading to altered local blood supply, and movement and resorption of the associated osseous elements. Local blood supply could conceivably be altered by migration of muscle attachments. Kelsey[10] has suggested movement of the segment as an explanation for the return of the original gonial angle after orthognathic surgery; that possibility has been partially confirmed by McNamara et al[5] and Yellich et al.[14] The current study, however, has shown that in addition, significant remodeling occurs. This supports the findings of Hoyte and Enlow[8] and Warner,[3] who stated that muscle forces directly influence bone form.

Throughout the duration of the study, bone resorption in Group AS was nearly twice as great as that observed in Group A, although this difference was not statistically significant. This difference might have been significant if a larger number of animals had been used. There are two possible explanations for this difference, one being the alteration in local blood supply. The other may be that inflammation induced by the mild surgical insult influenced the osseous remodeling. That surgical insult tends to alter the osteoblastic-osteoclastic balance is further supported by the fact that Group DR lost bone at the gonial angle even though the origin-to-insertion distance was not altered.

Post-treatment Observations

Throughout the experiment, the values for Group PT were not significantly different from control values. However, whereas the control group had both bone deposition and resorption in the area of the gonial angle, only bone deposition was observed in the PT Group. This may indicate a reversal of the typical pattern of remodeling observed in the other groups. Because the distance between the origin and insertion of the elevator musculature decreased in these animals following appliance removal, one could speculate that there was a deposition of bone at the gonial angle as a result.

The Group A animals and Group PT animals can be contrasted in an interesting way. The reactive response of shortening following experimental lengthening of a muscle (Group A) resulted in bone resorption, whereas spontaneous lengthening of a muscle following the shortening of the distance between the origin and insertion (Group PT) resulted in bone deposition. The differing responses of these two experimental groups in which there was no interruption of the vascular supply seem to indicate a close relationship between function and form in the nongrowing gonial region.

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